Critical Examination of the Conceptual Foundations of Classical Mechanics in the Light of Quantum Physics

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Abstract

As it is well known, classical mechanics consists of several basic features like determinism, reductionism, completeness of knowledge and mechanicism. In this article the basic assumptions are discussed which underlie those features. It is shown that these basic assumptions — though universally assumed up the beginnings of the XX century — are far from being obvious. Finally it is shown that —

to a certain extent — there is nothing wrong in assuming these basic postulates. Rather, the error lies in the epistemological absolutization of the theory, which was considered as a mirroring of Nature.

Keywords: Perfect determination, determinism, mechanicism, completeness, mirroring, causality.

1 Introduction

Classical mechanics (CM) is one of the greatest achievements of human knowledge. It is a compact building whose conceptual and mathematical aspects have been known and studied in all details and consequences, though the formation of the theory itself was a difficult process which took three centuries (XVII-XIX) to be completely achieved.

But, to the best of my knowledge, some basic — and sometimes only implicitly assumed — postulates of CM have not been subjected to critical examination — a state of affairs which can be partly explained by the implicit character of some of them. This situation, on the other hand, has as a consequence that all basic postulates of the theory have not been considered in their connection as a system — contrarily to what happens for the formal-

ism of the theory, which from the beginning of XIX century is presented in a systematic form. In fact, to the best of my knowledge, there is until today no handbook which introduces these postulates in systematic order at the beginning of the exposition[1].

Such an enterprise is possible today because quantum mechanics has shown, especially in the last twenty years, that several assumptions of CM are far away from being above a legitimate suspicion or a critical examination.

I will try to expose in a systematic form these assumptions. In section 2, I shall examine CM's determinism and the postulates from which it stems. In section 3 a similar analysis is devoted to reductionism, while section 4 shows that mechanicism is equivalent to determinism plus reductionism. Section 5 examines the postulate of the completeness of knowledge (and not of the completeness of the theory itself, a problem which today cannot be posed in this form). Sections 6–8 are devoted to the more general consequences of these assumptions while in section 9 some concluding remarks will follow.

[1]See [*LANDAU/LIFSHITZ* 1976a] [*GOLDSTEIN* 1950] [*HESTENES* 1986] [*KNUDSEN/HJORTH* 1995] for instance.

2 Determinism

Everybody admits that CM is deterministic. But determinism is a more complex assumption which supposes other, more basic postulates or principles.

2.1 Omnimoda determinatio

The most basic assumption of CM is the postulate of perfect determination which may be expressed as follows: all properties of a physical system are perfectly determined, where a *physical system* can be roughly understood as an object or a collection of objects (somehow interrelated) which can be (directly or indirectly) experienced, and a *property* as the value which can be assigned to a physical variable or observable. *Perfectly determined* means that each variable of the system has at all times a definite value.

This assumption was always implicitly made. For all 'classical' physicists it was so self-evident that it was even not worth of mention. In fact modern physicists — like Galilei, Newton, and many others — inherited such assumption from all past philosophy: Democritus, Plato, Aristotle, the middle-age philosophers until the modernity never thought differently but all assumed that all properties of being are determined (the problem was obviously to

determine what the main or true being is). In fact Kant says: all what exists is completely determined [*KANT* 1763, 85] [*KANT* 1787, B 599–602], which means that, between every possible predicate of an object and its negation, one of the pair must be actualized. Since every physical property can be reduced in a binary form (i.e. using what in quantum mechanics are called projectors) — for example 'moving at the speed of light' or 'not moving at the speed of light' (in some space–time context and by reference to a system, both to be specified) —, then the philosophical definition is a generalization of the physical one and, so far as physical objects are considered, they can been taken to be equivalent. For this examination Kant is an especially interesting example because it has been often told that his philosophy is strictly related with Newtonian mechanics. The latin traditional expression for the complete determination is *omnimoda determinatio* and can be found for example in [*BAUMGARTEN* 1739, par. 148].[2]

Now it turns out that quantum mechanics violates the *omnimoda determinatio* at least through the superposition principle[3]: In fact if a quantum

[2]On the problem see also Leibniz's letter to de Volder of april 1702 in [*LEIBNIZ* PS, 239].

[3]For argumentation of this point see chapters 24, 30 and 46 of [*AULETTA* 2000].

system can be in a superposition state, say of wave localized in an arbitrary region 1 and of another in an arbitrary but different region 2, then, following Kant, it is certainly impossible to say 'either it is in the region 1 or it is not' or 'either it is in the region 2 or it is not', or, more simply, 'either it is in the region 1 or it is in the region 2', i.e. quantum mechanics does not acknowledges a generalized exclusion disjunction[4]. There are no means to reduce such an indetermination to subjective ignorance, so that it must be taken as an ontologically basic feature of the theory.

2.2 Continuity

The *omnimoda determinatio* may be easily confused with determinism. But they are not equivalent: In fact one can conceive a 'classical' world where every 'state of the world' (roughly: the complex of all states of all systems within at a given instant) is in itself perfectly determined though without relationship with past and future states, in the sense that the world can jump from a state to another randomly. If this would be the case, nobody could speak of a deterministic evolution (for a more formal definition of

[4]On this specific point see [HARDEGREE 1979].

determinism see next subsection).

Therefore, in order to obtain determinism we also need continuity. This assumption is known as the principle of continuity and it states that the variables associated to a physical system are supposed to be continuous, which in physics means that, given two arbitrary values of a physical variable, all intermediate possible real values are also allowed.

The principle of continuity, though often not explicitly stated in handbooks, was widely used already from the early days of CM: one may remember here, for example, the use of the principle made by Galilei by the law of fall[5].

Obviously the point of major conflict between CM and quantum mechanics was continuity, which is rejected by the quantum postulate (the values of quantum observables can be discontinuous) and by the fact that quantum systems can jump[6].

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[5]See [*MACH* 1883, 130–131, 181] [*MACH* 1905, 223].

[6]The quantum postulate was assumed by Planck [PLANCK 1900a, PLANCK 1900b] and generalized by Bohr [BOHR 1913]. About the formalism of quantum jumps see [*CARMICHAEL* 1993].

2.3 Determinism

Sufficient and necessary conditions of determinism are the postulate of perfect determination and the principle of continuity. In fact, given the perfect determination of the state of a system at an arbitrary initial state, if its dynamic variables (for example the energy) are continuous, then also every future state of the system will be perfectly determined and unique, i.e. without alternatives or without branching[7]. As it is known, a mathematical formulation of this assumption is given by Hamilton's canonical equations, which in terms of Poisson brackets can be written

$$\dot{q} = \{H, q\}, \qquad \dot{p} = \{H, p\}. \tag{1}$$

The Hamiltonian H, the energy function of the system, fully describes the system and all its future (and past) evolution, and it is expressed in terms of the position q and the momentum p. Note, however, that determinism is not the same as predictability: in fact it is well known that, for a large class of problems, almost identical initial conditions can have very different solutions

[7] One may think at Laplace's dictum that nothing is uncertain: see [*CASSIRER* 1957, 134–35] [*EARMAN* 1986, 7]. The latter book represent a good analysis of classical determinism.

for later times [see also subsection 3.2].

Determinism too is an ancient philosophical concept, introduced probably by ancient atomism and further developed by ancient stoicism.

In quantum mechanics the Schrödinger equation is also deterministic, but here what evolves deterministically is an amplitude, i.e. it is — paradoxically — a determinism which is intrinsically probabilistic. In fact, in the general case, we cannot foresee what values the observables will have; we can only write their probability distributions. As we have already said, the break of continuity is a major feature of quantum mechanics. For this reason Bohr [BOHR 1928] [BOHR 1929] spoke of a break of determinism and of causality as such. Causality may be here understood in a strict and in a wide sense, following the distinction between determinism and predictability. In fact, in a strict sense it may be taken as equivalent to determinism. In a wide sense it may be understood as predictability, and then it should be rather taken as equivalent to mechanicism [see section 4] to the extent in which also linearity and separability are necessary in order to have a predictable future.

One could think that, behind perfect determination and continuity, determinism also supposes conservation laws. We may understand the problem of conservation in two forms:

i) nothing which is physical can disappear;

ii) in an isolated system certain physical quantities such as the angular momentum are conserved.

On the second point we shall return later [see subsection 5.1]. Point i) is a general statement about the conservation of energy (which obviously is a conserved quantity also in the second sense). In fact energy is the basic physical quantity which, following our physics, can be transformed but never destroyed, a fact that is expressed in a general form by Einstein's equation

$$E = mc^2, \tag{2}$$

which is valid also in the case of annihilation of particle–antiparticle pairs (in fact, as it is known, their mass is transformed in the energy of 'outgoing' photons).

In the statement i) it is the universe as a whole which is considered as a closed system. It is evident that this statement is a more basic one — but also a weaker one — than statement ii). In fact, we could think a world where there can be no strict conservation of the energy in the sense of statement ii) and notwithstanding would be deterministic. For instance, there could be an universal but unknown and unknowable 'ether' such that

all observable physical system lose part of their energy. Then the energy would be conserved in the sense of statement i) because a form of energy is transformed in another form by the action of ether, but it is not conserved in the sense of statement ii) because, for example, we could have a a physical law of this form:

$$\dot{p} = F - \alpha p, \tag{3}$$

where F is the force and α some parameter. Obviously the ‘path’ or the ‘trajectory’ of the every physical system should be always calculable, i.e. the loss of energy should follow strict laws and not be random. Otherwise the world could be not deterministic. On the other hand, as we have said, even if the ‘physics’ in this universe should be expressed in terms of equations like (3), the ether is not something which is outside of such an universe, so that, in a certain objective (or meta–physical) sense (God’s point of view?), proposition i) is satisfied. But the difficulty of this position is to admit the existence of something physical which in principle cannot be experienced.

3 Reductionism

Reductionism, as we shall see in that what follows, is another basic piece of CM and, as determinism, it supposes other assumptions which need to be preliminarily examined.

3.1 Materialism

One may wonder that the assumption of materialism is basic for CM since one may think that it is a metaphysical assumption without consequence or relevance upon a physical science as CM is. But this is not the case: CM is a mechanics, i.e. a theory of the motion of bodies and of the forces which act upon them. And a body is necessarily a material entity.

In fact the existence and the basic properties of matter were assumed and defined from the beginnings already by Galilei[8] and by Newton. In the third *regula philosophandi* of book III of the *Principia* [*NEWTON* 1687, 552–55], Newton makes a catalogue of properties of matter (bodies): Extension (a cartesian property), hardness, impenetrability, capacity to move, inertia[9].

[8] See [*CASSIRER* 1906, II, 387–89]. See also [*MACH* 1883, 248–49] [*HALL* 1954, 106–107].

[9] See [*KOYRÉ* 1957, ch. 7] for commentary.

About hardness, in [*NEWTON* 1704, 388–92] it is explained that the parts of all homogeneous hard bodies which fully touch one another stick together very strongly. From their cohesion Newton inferred that particles attract one another by some force, which in immediate contact is exceedingly strong. On the other hand all bodies seem to be composed of hard particles; for otherwise fluids, as water, would not freeze, or fluids as "spirit of nitre and mercury" would not become hard "by dissolving the mercury and evaporating the flegma". And therefore hardness can be reckoned as the property of all uncompounded matter. So far Newton. It is then evident that all fluids can be reduced to hard bodies by freezing or evaporating: In this case the particles cohere fully, which in turn means that some bodies are not hard only because they are to a certain extent rarefied, i.e. there is some vacuum between the particles[10]. In other words, following Newton, all matter can be reduced to some ground 'state' in which it is fully homogeneous and hence inelastic. In fact elasticity is possible only if there is some internal structure to the matter, which is excluded by the postulated homogeneity.

One may discuss — and Newton himself had no final position about[11] —

[10] An important difference with respect to Descartes [*KOYRÉ* 1968, 33–34, 1205–110].

[11] See the mentioned regula III.

if matter is a continuous medium divisible *in infinitum* or it is composed by elementary corpuscles which are strongly bound and fixed together by adhering to each other. However, the consequence is that, by full homogeneity and/or rigidity, in case of collision of two bodies moving at the same speed from opposite directions, they will coalesce at the point of collision (because fully inelastic).[12] One may say that the kinetic energy has been transformed in some activity of the particles composing the body, but precisely this is impossible because there is no internal structure and no possibility of the particles to translate, to rotate or vibrate relatively to one another[13]. In a general way note that Newton had not included the force as an intrinsic property of matter as such — i.e. forces can only act 'from outside' upon the matter. In fact Newton only attributes a *vis inertiæ* to the matter and says [*NEWTON* 1704, 397–98] that it "is a passive principle by which bodies persist in their motion or rest, receive motion in proportion to the force impressing it, and resist as much as they are resisted. By this principle alone there never could have been any motion in the world. Some other principle was necessary for putting bodies into motion; and now they are in motion,

[12]For examination see [*KOYRÉ* 1957, ch. 9].

[13]For all the problem of bodies' collision see [*MACH* 1883, 310–31].

some other principle is necessary for conserving the motion. For from the various composition of two motions, 'tis very certain that there is not always the same quantity of motion in the world. [...] it appears that motion may be got or lost. But by reason of the tenacity of the fluids, and attrition of their parts, and the weakness of elasticity in solids, motion is much more apt to be lost than got, and is always upon the decay. For bodies which are either absolutely hard, or so oft as to be void of elasticity, will not rebound from one other. Impenetrability makes them only stop. If two equal bodies meet directly *in vacuo*, they will by the laws of motion stop where they meet, and lose all their motion, and remain in rest, unless they be elastic, and receive new motion from their spring." Therefore Newton concludes [*NEWTON* 1704, 401–402] that it seems to him that "these particles [of matter] have not only a *vis inertiæ* ...but also that they are moved by certain active principles, such as is that of gravity, and that which causes fermentation, and the cohesion of bodies." As it is clear in the following pages of the *Optics* and in other places, these principles are due to the direct action of God. Therefore, one can understand that Leibniz, in his letter to the princess of Wales [*LEIBNIZ* PS, VII, 352], defend the conservation law of 'force and energy' against Newton. And it is interesting that, in his first an-

swer, Clark writes [*NEWTON* 1704, VII, 354] that God "not only composes or puts things together, but is himself the Author and continual Preserver of their original forces and moving powers".

Therefore we see that the materialism assumed since the early days of CM is far from being obvious, and the idea of a fully homogeneous matter was very soon abandoned. In quantum mechanics there can be no question of perfectly hard and localized corpuscles: To quantum entities is intrinsic a wave-like behavior or some fuzziness. Therefore it is better to speak of extended particles[14]. On the other hand properties as the hardness or impenetrability seem inadequate to microentities as we know them now.

3.2 Linearity

Linearity is an important property of classical systems. In itself it is essentially a mathematical property, because it consists in the requirement that the basic equations of CM must be linear, i.e. reducible to a form like

$$a_0(x)y^{(n)} + a_1(x)y^{(n-1)} + \ldots + a_n(x)y = f(x), \tag{4}$$

[14]On this point see chapters chapters 30 and 33 of [*AULETTA* 2000].

where $a_0(x), a_1(x), \ldots, a_n(x)$ are coefficients, $f(x)$ is some function and $y^{(n)}$ the n–th derivative of y. But linearity has a conceptual relevance to the extent in which it excludes feed–back, i.e. self–increasing processes.

It is linearity which allows an important aspect of the 'reductionistic methodology' of CM: the factorization between component 'elements' of a system, for example the decomposition of motion in components by Galilei, the decomposition of forces by Newton or the decomposition of harmonic components[15]. In other words if the cause (the force) C_1 produces the effect (the acceleration) E_1 and the cause (the force) C_2 the effect (the acceleration) E_2, then $\mathrm{C}_1 + \mathrm{C}_2$ produces $\mathrm{E}_1 + \mathrm{E}_2$. This principle is often called principle of (classical) superposition.

One could think that in CM a small perturbation on a given system or the weak interaction of this with another system only causes a small deviation in the trajectory of the system in the phase space, such that, normally, the system will 'absorb' it and return on the ancient deterministic path. But a perfect classical system can show such a dependence on initial condition that its evolution can be chaotic (in fact in chaotic regime this dependence

[15] For these examples see [*MACH* 1883, 144–45, 191–92].

is expressed by a strong divergence of initial very close, indistinguishable trajectories in phase space). Note that, in the chaos theory, chaos itself is intrinsic and deterministic and not stochastic and extrinsic — in other words it is not due to random fluctuations of the environment or to noise[16]. In fact there can be chaos also by Hamiltonian systems.

Linearity is not violated by quantum mechanics. In fact Schrödinger equation is linear, and any attempt to introduce non–linear terms in this equation has up to now failed[17].

3.3 Separability

Separability is another key feature of CM. But it is again an implicit assumption and firstly in 1935, as CM was confronted with quantum mechanics, it

[16]On the point see [*SCHUSTER* 1988] [*RUELLE* 1989].

[17]A non–linear equation for quantum mechanics was proposed in [BIALYNICKI-B./MYCIELSKI 1976]. Shimony proposed an experiment aiming to verify if there are non–linear terms and if they have the magnitude proposed by Bialynicki–Birula and Mycielski [SHIMONY 1979]. A later experiment performed on these outlines tendentially excludes such terms [SHULL *et al.* 1980]. Obviously this does not mean that the methods of quantum mechanics and chaos theory cannot be combined. They can be, and actually are unified in what is today known as 'quantum chaos'.

was stated explicitly by Einstein and co–workers [EINSTEIN *et al.* 1935]. The principle of separability may be expressed in the following way: given two non–interacting physical systems, all their physical properties are separately determined, or, in other terms, the result of a measurement on one system cannot depend on a measurement performed on the other system. The meaning of the principle is the following: two systems can be interdependent only through a physical interaction (for example some form of potential energy).

Again quantum mechanics violates the separability principle by a consequence of the superposition principle for multiparticle systems: entanglement. In fact for entangled subsystems, it is not possible to factorize the probabilities of the outcomes of experiments performed on each subsystem locally. In other words, probabilities calculated on one of two 'distant' subsystems, even if they do not physically interact, are not independent[18].

[18] There exists a wide literature on this subject. For a summary see chapters 31 and 34–35 of [*AULETTA* 2000].

3.4 Reductionism

Now we may summarize the results of this section by saying that materialism plus linearity plus separability are sufficient and necessary conditions of reductionism. Roughly speaking, by reductionism it is usually meant that a system is given as the "sum" of its constituent components, or, equivalently, that any system can be divided into "elementary" parts. The aim of reductionism is then to find the ultimate elements of matter which cannot be further reduced. To our knowledge there is no certainty (and even doubts) that such a task will ever be accomplished. One speaks today, for example, of quarks and leptons as 'divisible' particles. However, quantum mechanics violates this type of reductionism because it violates the separability principle — and does not, as we have seen, violates linearity (leaving aside the problem of materialism). In fact it is evident that, if separability is violated, no reduction of a whole to 'parts' is possible because the parts could be not treated as independent systems.

On the other hand, reductionism can be also understood as the reduction of more complex theories and sciences as chemistry and biology to physics and especially to quantum mechanics (this may be called *epistemological* or

methodological reductionism relatively to the first type, which may be called *ontological* reductionism). It is true that quantum mechanics shows its effects (entanglement, for example) also at mesoscopic level. But this means anyway that the mesoscopic or the macroscopic world are only 'illusions', apparent realities. In fact the process of decoherence and especially of localization which goes together with decoherence, especially when the number and the complexity of systems grows, is throughout objective[19]. On the other hand, no necessity arises to conceive of methodological reductionism as a one–way operation: If one speaks of reduction to more elementary objects, one should speak — with more reason — of a methodological reduction of microscopic equations for the constituents of a system (via coarse graining) to differential equations for macroscopic variables, and from these (via numerical calculations of Poincaré sections) to low dimensional Poincaré maps[20].

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[19]See chapters 17 and 24–25 of [*AULETTA* 2000].

[20]See [*SCHUSTER* 1988, 14–16] [*BERGÉ et al.* 1984, 63–78].

4 Mechanicism

Sufficient and necessary conditions of mechanicism are determinism and reductionism. No 'classical' mechanics can violate the one or the other. In facts mechanicism consists in the theory that, given an input (some force) we have a fully automatic and proportional output (some acceleration), which would be surely impossible if the whole system were more than the sum of the 'parts' (i.e. if the requirement of reductionism would be violated), or if it would show a random reaction to a given action (i.e. if the requirement of determinism would be violated). On the other hand, a system satisfying the features of determinism and reductionism would be necessarily mechanic. In fact we distinguish the behavior of organic life from a pure mechanical behavior exactly through the violation of the one or of the other requirement or of both.

5 Completeness

The possibility of a complete knowledge in CM is dependent on other assumptions, namely determinism and isolability. Let us examine firstly the assumption of isolability.

5.1 Isolability

CM assumes that isolated systems are possible; i.e. that we can always theoretically treat and experimentally (at least in principle) generate a system without physical interdependence with other systems or with the environment. It is the isolability which guarantees conservation laws of pertinent quantities. In fact angular momentum, energy or motion can be conserved only if the system is considered as isolated from others, i.e. there is no interaction such as to cause dispersion or no action of an external force such as to change its motion. Quantum mechanics does not apparently violate this assumption. But it may be asked if there are actually isolated quantum–mechanical systems and even more if macroscopic systems can be fully isolated.

5.2 Completeness

In CM it is supposed that one can perfectly know (at least in principle) all properties of a given system. In other words the properties of the object system can be perfectly measured. Therefore it is postulated that the measurement errors can be — at least in principle — always reduced below

an arbitrarily small quantity ϵ. Hence this assumption may be called the postulate of reduction to zero of the measurement error.

Note that this postulate is not a direct consequence of the principle of perfect determination only, because it can be the case that a system is objectively but not subjectively perfectly determined. It supposes continuity too: in fact if the pertinent variables were discontinuous, then we could not approximate to a point-like value in a given interval. Hence it presupposes determinism (which, as we know, is equivalent to perfect determination plus continuity). But isolability too: In fact if the system could never be really isolated, we could never know its properties perfectly, even not in a very large time interval, because, during the flow of time, it may be that small interactions with external systems cause small uncertainties in the measurement results so that — even if these uncertainties do not cumulate — one cannot go beyond a certain threshold.

If we speak of the perfect knowledge of all properties of a given system at the same time, then this assumption is obviously violated in quantum mechanics through the uncertainty principle. In fact this principle states that, by increasing the knowledge or the determination of an observable of a conjugate pair, the complementary observable must proportionally increase

its uncertainty.

6 Classical Mechanics

We can now draw the first general conclusion from the above analysis: CM consists of both mechanicism and completeness (of knowledge). There is no doubt that there can be no CM without mechanicism. But one may think that completeness is not a necessary condition of CM. This is not the case because CM is actually so built that a perfect transparency of the object system to the knowledge corresponds to the perfect ontological determination of it. But it could also be not otherwise: For a physicist the primary questions are objective and not subjective: In order to admit an incomplete knowledge together with the assumption of mechanicism — and hence of a perfect ontological determination —, one should know some basic limitations of human mind, which in principle exclude the possibility for human beings of perfectly knowing systems which are objectively perfectly determined. But no such problems have ever been found.

7 Classical Gnoseology

Classical mechanics has been developed together with what may be called a *classical* gnoseology — i. e. the gnoseology of Galilei, Spinoza, Newton, Kant and many others. Classical gnoseology certainly supposes the completeness of knowledge, i.e. that the properties of being can be perfectly known. But it also supposes what may be called a 'mirroring' theory. Explicitly: classical gnoseology considers the act of knowledge as a mirroring of the properties of the object.

In other words, knowledge is understood as a reproduction of objective and given data and not as a form of interaction between subject and object. This understanding of knowledge is very ancient and can also be found by philosophers as Plato. Several philosophy schools have shared this pointof view. Obviously, there is no agreement between several schools about what is the being to be reproduced (ideas as platonic substances, atoms, forms, material objects, and so on). When knowledge is so understod, then one assigns to the subject a mere reproductive and representative role.

However this view is no so evident. In fact pragmatism[21] proposes a

[21] On this point see [PEIRCE 1878a, PEIRCE 1878b].

different theory of knowledge. It is seen as a problems–solving enterprise which, by starting with a problem, assumes a hypothesis (under many others possible ones) because it can solve in a satisfactory manner the conflicts or the contradictions arisen from the problem itself. This is not the place where to examine this subject in details, but I think that this explanation of how theories work and are generated is far more satisfactory for describing scientific knowledge than the traditional, classical approach. I only wish to stress following aspects of this explanation:

i) Subject and object are not understood as static beings and knowledge not as a form of translation of data into a mind (and how would it be possible?).

ii) Experience is dynamic and comprehends 'subject' and 'object'[22].

iii) Knowledge is open and never represents a final answer.

iv) Knowledge is a form of praxis and the theory is not completely separated from other human activities.

[22] On this point see [*DEWEY* 1929].

8 Classical Philosophy

Classical philosophy, the main stream in XVII-XVIII centuries, is compound of CM plus classical gnoseology. That philosophers and physicists of that age have acknowledged all or almost all the above principles can be seen from the following examples. Let us first take Kant's examination of the ontological proof of the existence of God[23]. Kant says that when I affirm that *God exists*, I add no new predicate to the concept of God; rather I pose only the subject (God) in itself with all his predicates, i.e. the object, in relationship with my concept. Both, the object and the concept, must contain the same. In other words, in Kant's terminology, what is real does not contain something more than what is only possible (the concept). If the object should contain more than the concept, then the latter will not express the whole object and will therefore be not adequate to this object. So far Kant. In this argumentation, the *ominimoda determinatio* is always taken for granted and three additional principles are (implicitly) assumed: that the concept is isomorphic with the object (the predicates contained in the concept corresponds to properties that the object has: it is the mirroring theory); that therefore an adequate

[23] In [*KANT* 1787, B 627].

knowledge must be complete (all properties of the object must be considered in the concept); and finally that one can consider the object 'in itself', i.e. in complete isolation from other objects (it is the assumption of isolation). Since this is a general arguments which goes beyond to the specific problem of the existence of God, one can consider the object without relationship with the other objects of the universe. It is true that in [*KANT* 1787, B 599–602] one speaks of the *omnimoda determinatio* as an ideal, but in the above proof it is taken as an ontological fact.

To my knowledge Kant never rejected the continuity and perhaps he had nothing against linearity. He surely assumed a form of materialism: Since our knowledge can only happen in an experience which is intrinsic spatio–temporal [*KANT* 1787, B 33–73], then the objects of knowledge can only be bodies; and in fact Kant discusses the problem of matter [*KANT* 1787, B 230, 277–78] and excludes that the subject of knowledge can also be object of knowledge [*KANT* 1787, B 152–165]. Of all above postulates only separability remains; but, as already said, it has been the object of scientific analysis only in the 1930s.

Then let us also briefly discuss the assumptions (but not the details of the argumentation) of the article of Einstein and co–workers [EINSTEIN *et al.* 1935].

There is no doubt that it acknowledges the *omnimoda determinatio*. In fact the aim of the article is to show that there can be elements of the reality which cannot be represented in quantum mechanics due to its 'uncertain' character (uncertainty principle) — in fact, as it is well known, Einstein thought that quantum mechanics could only represent a statistical (and therefore incomplete) theory of microentities. Specifically, the aim of the article is to show that quantum mechanics violates a sufficient condition of reality, which may be expressed as follows: If, without in any way disturbing a system, we can predict with probability equal to unity the value of a physical quantity, then there exists an element of the physical reality corresponding to this physical quantity. It is evident that two things are supposed here: first that the reality is perfectly determined in itself; second, that one can also know it perfectly (our completeness condition). Continuity is evidently acknowledged in the formal development of the argument. So there is no doubt that the article also acknowledged determinism (= *omnimoda determinatio* + continuity). Though no word is said about materialism and linearity, the core of the article is represented by a strong defense of the principle of separability (here for the first time formulated), so that one can suppose that reductionism too was a valid assumption for Einstein and co–workers.

But the article goes even further. In fact two definitions are formulated with great emphasis at the beginning: That of correctness and that of completeness. It is said that a theory is totally correct if every element of the theory has a counterpart in reality: In other words a totally correct theory is one without superfluous theoretical terms. It is evident that the necessary condition for assuming this definition is the mirroring theory: If theories could not mirror reality, could also not mirror reality correctly. About completeness it is said that a theory is complete if every element of reality has a counterpart in it — it is evident that correctness together with completeness establish an equivalence relationship between physical theory and reality. This definition of the completeness of a theory is much stronger than that previously formulated. In conclusion CM and classical gnoseology, and therefore classical philosophy as such, are defended in Einstein's article.

It is very interesting that Kant and Einstein — both scientists and philosophers — defend essentially the body of classical philosophy, and that the latter does it in open conflict with quantum mechanics.

9 Conclusions

Summing up, CM can be schematically represented as in the figure.

CM has been for three centuries the model of what Science is and should be. Then it is a little surprising that its basic assumptions were assumed without critical examination. But two points are here very important:

i) Without quantum mechanics and its consequences nobody would have perceived the problems hidden in assumptions which ultimately stem from the common sense or from a refinement of the ordinary experience about macroscopic objects. This does not mean at all that this experience is in itself wrong. We live and act in a macroscopic world where the struggle for life is the most important thing, and for this practical purpose it makes no sense — and it is perhaps even dangerous — to assume, for instance, that objects are partly not perfectly determined or fuzzy[24]

ii) But neither CM's assumptions are wrong as such. CM has been in fact

[24] And, with high probability, also macroscopic objects are partly fuzzy; in fact one has shown theoretically and finally experimentally that, at mesoscopic level, 'Schrödinger cats' are possible [MONROE *et al.* 1996] [BRUNE *et al.* 1996].

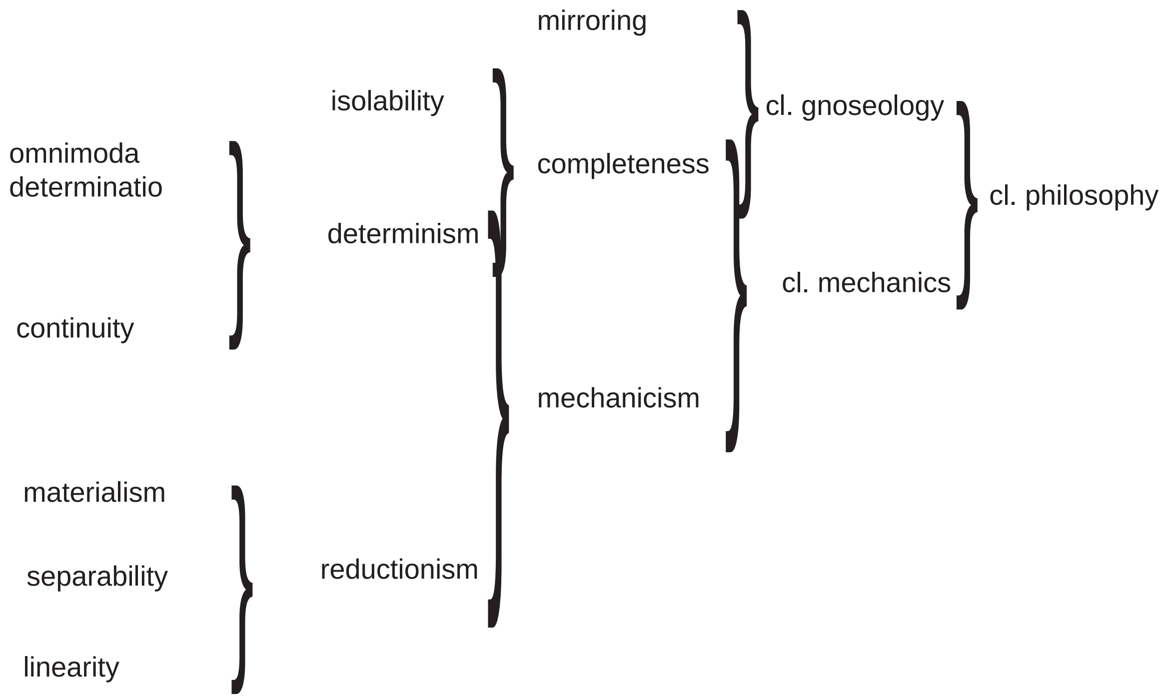

Figure 1: Schematic representation of the basic postulates and principles of CM.

a powerful tool in order to explore Nature and establish some basic features of the physical world. Stated in other terms, for all that one knew at that time, CM worked — and still works — very well. What is wrong is only the supposition that CM's assumptions and laws are objective in the sense that they mirror what Nature is in itself. In other words, what was and is wrong about CM is a 'mirroring' gnoseology and epistemology which has produced an absolutisation of the this physical theory. In other words, we have here a confirmation *e contrario* of the rightness of the point of view of pragmatism.

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